Towards a Cloud-Based Controller for Data-Driven Service Orchestration in Smart Manufacturing

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***Abstract*—The orchestration of smart manufacturing service operations and processes arises as a challenging step in the realization of the Industry 4.0 vision. This paper presents the work in progress towards the specifications of a controlling environment for data-driven orchestration of software services in future smart manufacturing scenarios. The paper discusses the role and significance of multi-aspect data in the management of manufacturing operations and proposes a reference architecture for controlling the orchestration of the respective data services, following the work that has been conducted in the context of the EU-funded project DISRUPT.**

***Index Terms*—Smart manufacturing, data-driven service orchestration, controller**

I. Introduction

Digitisation drives the next industrial revolution towards sustainable manufacturing. This digital transformation, commonly referred to with the term Industry 4.0 (I4.0) [1], builds upon innovative strategies and techniques, in which controlling the enterprise operations, both at the manufacturing and the supply chain level, can increase the effectiveness and optimize the performance of the manufacturing industry. The I4.0 vision challenges the way that these enterprise operations will be managed within the context of a smart manufacturing industry ecosystem. It also offers the potential for novel business models and interactions, in which data coming from products, services and processes maintains a dominant role in advancing the monetization value for the respective organisations.

Existing efforts in formalizing the I4.0 concepts have been reflected in the respective reference architectures, such as RAMI 4.0 [2] or IIRA [3]. Both architectures aim to advance the manufacturing operations in the context of a digital manufacturing ecosystem and provide additional intelligence towards implementing the fundamental manufacturing industry scenarios, such as the smart factory, the smart product lifecycle and the smart supply chain [4]. However, the distribution of intelligence across the manufacturing resources has resulted in increased data-oriented needs to drive the orchestration and optimization of relevant operations and processes, in order to control a highly data-driven smart manufacturing environment.

To address these needs, the EU-funded H2020 project DISRUPT[1] has adopted an architectural approach where data becomes a prime citizen in service orchestration aiming to deliver smart data management throughout the traditional manufacturing pyramid. This will be enabled by leveraging sophisticated technologies, which include data analytics, formal models and complex event processing [5], [6]. To achieve their seamless integration, a Cloud-based controller overseeing the data ecosystem is envisioned as the key mechanism that handles the data deluge in an orderly manner while delivering data-driven service orchestration. The rest of this paper presents work in progress in DISRUPT to identify the requirements for such data-driven service orchestration and propose an initial approach towards the architectural specification of the key elements of a Cloud-based controller.

[1] http://www.disrupt-project.eu/

II. Key Requirements for Data-driven Service Orchestration

Service orchestration has always been a concern for the Service-Oriented computing paradigm. In previous years, lots of research has dealt with various issues related to service orchestration [7]–[9]. In the I4.0 envisioned pathway for smart manufacturing, data and the ability to extract information from diverse volumes of data become a prime issue. The need for data-driven approaches is also echoed in a recent discussion paper by the Big Data Value Association [4]. In this respect, a data-driven service-orchestration approach becomes a foundation stone in the integration of different services that can deliver software architectures for a smart manufacturing environment [10].

Following an analysis of the DISRUPT use cases [5], a smart manufacturing ecosystem has to deal with *multisource*, *multiscale* and *multivariate* data. The reasons are briefly summarized below:

- **Multisource data:** A number of information sources are involved in data collection, ranging from Internet-of-Things (IoT) and control systems, to Cyber-Physical Systems (CPS), Enterprise Information Systems (EIS) and other manufacturing assets (e.g., machines, production lines, inventories, etc).
- **Multiscale data:** Different types of data from various operations and processes are involved, which span across multiple levels of the industrial automation hierarchy, from low level machines, to production lines and supply chain networks, up to the whole factory digital world.

- **Multivariate data:** The data exhibit different variables, through which it can be considered and processed, such as temporal aspects that affect the selection of the appropriate collection mechanisms or the target resources that this data is referred with respect to the decisions that need to be made.

As a result, the goal of efficient data-driven service orchestration requires work around the following dimensions:

1) The collection of semantically connected multisource, multiscale and multivariant data across the smart manufacturing industry: the production of huge volumes of such data along the whole range of the enterprise operations requires improved controlling mechanisms for managing big data integration and achieving semantic interoperability across the smart manufacturing concepts.
2) The use case driven flexible aggregation of smart manufacturing data: smart manufacturing entails more accurate and comprehensive control on situation awareness for the decision makers and the stakeholders in the industry to enable them assess the impact of disruptions on the current production and supply chain capabilities.
3) The orchestration of the decision-making mechanisms to effectively handle disruptions: the employment of data analytics, multilevel simulation and process optimization techniques requires mechanisms that enable manufacturers in maintaining the control of the information flow towards the selection of appropriate actions that relax the impact of disruptions and maximize operational efficiency.

The next sections describe how these requirements drive the specification of a cloud-based controller for service orchestration in a data-driven smart manufacturing environment.

III. The role of controller in the data lifecycle

A cloud-based controller for data-driven service orchestration may comprise the foundation of the central unit in future systems for smart manufacturing. Such a component will deal with the orchestration of the service processes for the collaboration among the individual capabilities found in I4.0-enabled manufacturing ecosystems. It can cope with increasing data demand by harnessing the power of Cloud computing.

The controller acts as the facilitator for the integration and interoperability of distributed capabilities and datasets in the envisaged service-based and data-driven environment of smart manufacturing. It can play a key role in the implementation of intelligent business cases and the validation of the fundamental business goals and Key Performance Indicators (KPIs), which span across the management of manufacturing and supply chain operations. Such goals and KPIs, which include the number of delayed and postponed material requirements orders or the changes in production schedules and product orders, can be better described in the context of knowledge models.

Specifically, the representation of the manufacturing knowledge assists in the proper management and interpretation of data for making informed decisions across the enterprise operations. The controller plays a key role here, as it should be able to bring the modelling experience into the deployment setting of smart factories. In this paper, the controller is positioned in the context of managing the data processes of the generic data lifecycle, as depicted in Fig. 1.

As shown in Fig. 1, the controller employs mechanisms to configure the type of data that should be collected from existing EIS and IoT infrastructures deployed in the plant floor or across the supply networks. On the processing level, smart controlling services are required to orchestrate the data analytics part towards identifying disruptive events and their impact on the current business KPIs. In the same sense, a cloud-based controller should handle the execution of data driven simulation and optimisation techniques that guide manufacturing experts in making informed decisions on how to interpret the observed or expected disruptions and undertake the necessary actions to address them. This is realized through the controlling services offered at the data distribution level, in which the experts knowledge on required decisions is communicated to both human agents and software systems to enact the relevant actions. Along these steps, the controller requires the development of mechanisms (at the data management level) that govern the data storage, preservation and access control services for the datasets collected from the manufacturing environment or produced as a result of intelligent decision support processes, possibly by leveraging appropriate cloud resources.

Through the involvement of the controller in the various stages of this data lifecycle, data-driven orchestration of managing services for the manufacturing operations can be developed. More specifically, the controller provides an overall view of the current operational status and capacity of a smart factory organization within the manufacturing processes and across the connected supply chain networks. The controller plays a connecting role in bringing the identified disruptions into the attention of the responsible incident handling teams. This capability is becoming more important if one thinks of the fact that the analysis of the disruptions drives the investigation of the causes of these disruptions and their impact on the current production capacity. Such functionalities comprise an integral part of modern decision management systems, as they support the respective personnel in understanding the causes of the disruptions and address them in the most efficient and effective manner.

The cloud-based controller is also an important ingredient on the decision making process. In modern manufacturing environments, decision making requires innovation on how multisource, multivariate and multiscale datasets could potentially drive the handling of disruptions. The goal is to provide appropriate alternatives through large-scale simulation and optimisation technologies. The controller stands on a central position in this case, as it provides key features towards the integration of individual capabilities it can support for the implementation of customized data-driven manufacturing management operations, with the aim to optimize key perfor-

Fig. 1. The lifecycle of multisource, multiscale and multivariate manufacturing data.

mance metrics and achieve the desired business level goals.

IV. Towards a Cloud Controller Reference Architecture

This section presents the first experiences from the development of a cloud-based controller in the context of the DISRUPT project. Initially, the main architectural elements of a cloud-based controller for service orchestration in a data driven digital manufacturing environment have been specified. The respective architecture view is presented in Fig. 2.

The controller is implemented following a Service-Oriented architecture approach. Its architecture distinguishes between three layers. Starting from the bottom of Fig. 2, the Data Storage Layer hosts the databases required in the cloud-based controller to accomplish the intended tasks. The main database consists of the Knowledge Base, which hosts the models expressing the knowledge and the relations among the different concepts, entities and resources in a manufacturing and supply chain environment. Other elements in this layer include the Decision Support Database, which supports the orchestration of the decision making processes, the DISRUPT Events storage area, which maintains the knowledge about the identified disruptive events and the User Management store to host the list of the DISRUPT users profiles. It is expected that the realization of the Data Storage Layer makes use of cloud computing resources.

On top of this layer, the Service Logic Layer hosts the software components that enable the controller to execute its functional capabilities, as presented in the previous section. Thus, this layer offers the connection with the lower layer, through the Data Access Component. Then, the Status Manufacturing Component responds to requests from other components on the current value and capacity of all the resources and entities related to a set of operations. Such values are retrieved in real-time by connecting this component with the Data Collection Connector to build the operational status of the manufacturing and supply chain environment at given time scales. Container-based technologies based on the cloud could be used for the deployment of the components within this layer.

The main components of this architecture are the Decision Support System (DSS) Manager and the Event Details Component. The DSS Manager acts as an orchestrator of the decision making mechanisms (i.e., simulation, optimization, etc.) that assess the impact of disruptive events on the manufacturing performance indicators and propose alternatives for restoring their optimal values. The controller uses the Event Details Component to manage the information about such events.

The Controller Service Manager is used to manage the flow of requests from the upper Service Access Layer components. This is responsible for maintaining the status of the controller processes and linking to the User Manager component, the Notification Manager and the CPS Connector. The latter two components assist in the actualisation of decisions made by the DISRUPT stakeholders, either manually (e.g., the Notification Manager instructs the respective actors on the elements of decisions) or automatically (e.g., the CPS Connector configures cyber-physical systems on the enactment of rules to implement the decisions).

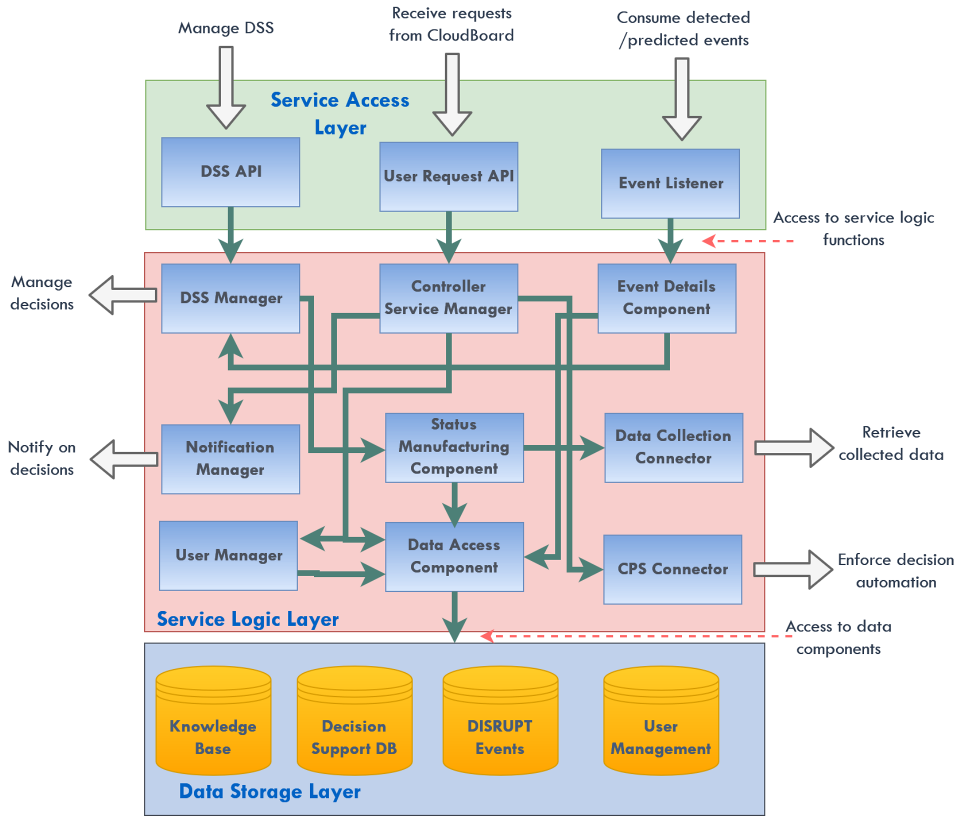

Fig. 2. The high level architecture of a data-driven service orchestration controller.

Finally, the upper Service Access Layer defines a set of components for allowing the controller to expose the intended capabilities to other service modules and user interfaces. These include the DSS interface (to connect with the DSS modules), the User Request interface (which facilitates the communication with the user driven actions through a dashboard or a user-interface) and the Event Listener (which enables the controller to collect disruptive events from external components).

V. Conclusion

This paper discussed the specifications of a software controlling mechanism for data-driven service orchestration in future manufacturing environments and presented the main architectural elements that compose such a controller. The importance of data-driven service orchestration in improving the decision making processes in smart manufacturing ecosystems has been highlighted. The specifications described in this paper comprise a work in progress, which is continuously conducted in the context of the EU-funded DISRUPT project. The next steps involve the instantiation of the proposed reference architecture for two industry scenarios and the validation of key implementations with critical stakeholders in the decision making path. By introducing and experimenting with this approach, the aim is to showcase the capabilities of data-oriented service orchestration towards the support of intelligent industrial scenarios for disruption management in smart manufacturing.

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